THE SUN AND STARS[1]

VIII.

FOR the purpose of this lecture I have ventured to make a revision of the classification which has been suggested by Dr. Vogel. I should tell you, with reference to this question of classification, that Rutherford started it; then the German physicist, Prof. Zöllner, recommended a certain line of arrangement which practically had been adopted by Father Secchi. I afterwards saw grounds for saying that that line of arrangement, or sequence, was apparently a very just one, because it seemed, from some considerations I brought forward, that it really arranges the stars in the order in which the various phenomena would be produced in the atmosphere of any one of them; that is to say, that it was a true evolutionary line starting from the conditions of highest temperature. Others have followed in the same track since, including Dr. Vogel; but, so far as I can make out, any credit which is due to the existing arrangement is due to Father Secchi and to Prof. Zöllner.

I will give you the arrangement, which I think will perhaps bring the facts in the most clear way before you.

We have, then, the first class of stars with broad absorption-lines and very few of them, and a remarkable absence of general absorption at the blue end of the spectrum. Next we have a second class, in which the lines are more numerous, and they are thinner. In this class come our sun, Arcturus, Aldebaran, and Capella.

Then we pass from absorption-lines altogether, and in the third class we have stars with flutings, of which the darkest part and sharpest edge of the fluting lie towards the violet part of the spectrum. Of these stars we have α Herculis and α Orionis as examples.

Then we have another set of fluted stars in which the opposite holds good. The darkest part and sharpest edge of the fluting are to the right, towards the red end of each fluting. And the stars of this class are faint.

In those four classes we nearly exhaust all those forty or fifty millions of stars in the heavens which shine, and which we can study by means of a telescope.

Afterwards we come to stars with bright lines, or the fifth class; and this we must divide into two—A and B.

In sub-class A the bright lines are always lines of hydrogen, such as we have in the chromosphere of the sun. Many of these stars, as we shall see by and by, which are characterised by such a spectrum as this are variable stars; not all.

In sub-class B the lines are not lines of hydrogen, and I may say that up to the present moment the origin of these lines is not known. There are, I think, at the present moment about half a dozen stars known with spectra of this character.

So much, then, for a general view. We have four classes of stars determined by absorption—two, line absorption; two, fluting absorption; first, broad lines; second, thin lines; first, flutings with the sharp dark edge to the left; then, flutings with the sharp dark edge to the right. Then in the last class we leave absorption-lines altogether and get to bright lines, and we get two sub-classes—those which obviously contain incandescent hydrogen, and those which as obviously contain something else.

Just a word or two on each of these two classes.

The stars with dark thick lines can be best shown by this diagram, which I owe to the kindness of Dr. Huggins. You

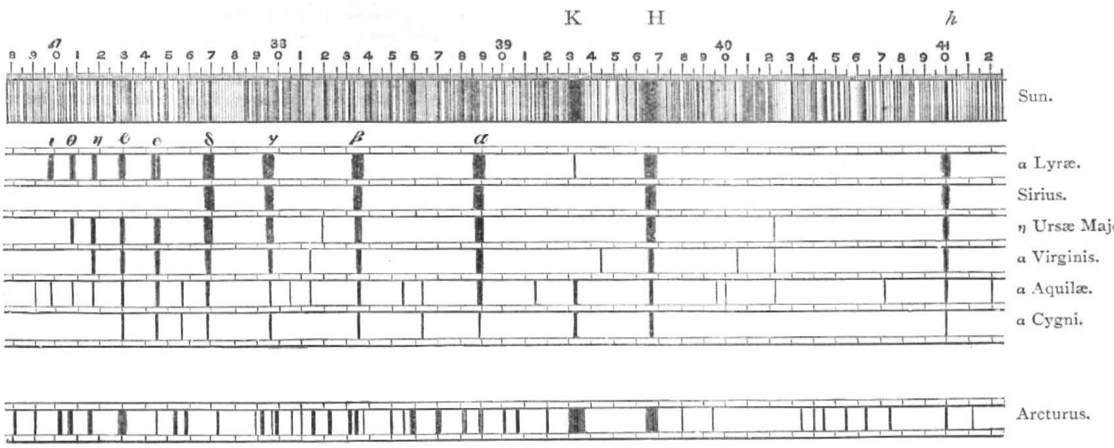

FIG. 22.—Stellar spectra (Huggins). In this diagram the spectrum of the sun is given at the top so that the spectra of the stars can be compared with it. The spectra of the stars are reduced from photographs, and the order of arrangement has been determined by the gradual thinning of the chief lines.

will see the difference between the thick absorption-lines and the thin ones, and you will remember that although stars may have the absorption-lines of identical wave-lengths, the thickness of these lines in the different stars may vary from one star to the other. Then we have the solar spectrum, the thickest lines of which are H and K, already referred to, in the ultra-violet portion.

The remarkable thing about the stars of the first class is that in some of them H is seen alone. In others H is seen with K thin, and in others H is seen with K almost as thick as itself. These lines are supposed to be due to the absorption of calcium. When calcium was studied in the laboratory a good many years ago, it was found that, at the temperature of the electric arc, the important brilliant line of calcium—the line which outshone all the others—was in the blue part of the sprectrum, and that the two lines which are most important, the two broadest lines, in the solar spectrum, are hardly seen at all in the spectrum unless the temperature of a very powerful induction coil be employed. Under these circumstances one may get the same relative importance given to the lines H and K in the violet which one gets with regard to the line in the blue as seen ordinarily, but only when the most tremendous means available to us are taken to secure what we consider to be the highest temperature.

On that ground it was prophesied that if the spectra of stars were ever photographed, probably some might be found hot enough to deal with those bright lines, H and K, in exactly the same way that the electric spark did; that is to say, that as in our laboratories we can get at a high temperature H and K obviously more brilliant than the blue line, whereas at low temperatures H and K are not seen at all, so we may anticipate similar results in the stars; if we can get stars very much hotter than any electric spark which we can obtain here, we might get H and K in different proportions, or each seen alone.

Now you see that prophecy has been fulfilled in this respect—that there are stars in which we get H alone without K, and we get different proportions of K added, as you can get different proportions of milk and sugar in a cup of tea.

Nor is that all. I am bound to tell you one other very curious fact. Since it was obvious when these stars were photographed that we were *really photographing the result of an increased* temperature; another prophecy was hazarded, and that was, that when, during an eclipse, the very brightest portion of the sun's atmosphere should be photographed in the ultra-violet and violet the spectrum would probably be very closely represented by the spectrum of these hottest stars. These photographs by

[1] A Course of Lectures to Working Men delivered by J. Norman Lockyer, F.R.S., at the Museum of Practical Geology Revised from shorthand notes. Continued from p. 207.

Dr. Huggins of course only include the violet and the ultra-violet.

This is the place to tell you that in the eclipse of 1882 most of these lines which you see in the spectrum of Sirius and α Lyræ—lines which are entirely cloaked in the ordinary spectrum of the one, and in most of the other stars—was actually photographed in the hottest part of the sun's atmosphere during that eclipse; so that you see that there were two prophecies with regard to this set of lines, both of which were fulfilled.

Now, when in science a working hypothesis suggests a certain result under certain conditions—enables us to prophecy in fact, and the prophecy comes true (that is essential)—we have a right to believe that the hypothesis may be well founded.

Those, therefore, who hold that these differences are due to temperature, have considered their opinions to be considerably fortified by those two fulfilments of prophecy to which I have referred.

You see in the diagram that although in the upper spectra representing Sirius and α Lyræ the lines are very thick, as those particular lines thin out other lines come in; so that in passing down the diagram from the upper horizon to the lower one, we get two conditions of things—one which we leave when we get few lines thick, and another which we reach where we get a very considerable number of lines thin, as many people believe because these substances gradually, by reduction of temperature in the atmosphere of the star, have gone into combination with themselves or something else, and formed other more complex bodies, which give us of course new lines practically at the expense of the old ones. There then we get on that diagram representing a part of Dr. Huggins's magnificent work, the possible explanation of the passage from Class I. to Class II.

A reference to the two classes of absorption-spectra we owe chiefly to the work of Dunér and Vogel may very fitly follow these records of Dr. Huggins's work.

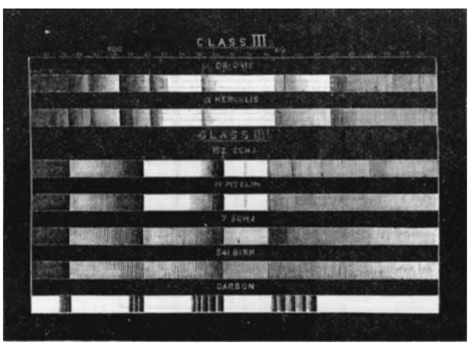

Fig 23.—Dunér's spectra of Class III. compared with carbon.

I did not tell you (there was no necessity for it at the time) that one of the rarest substances apparently in the atmosphere of the sun at the present time is carbon. There is a possible trace of carbon in the sun's atmosphere I think, but the assertion depends upon the existence of a single fluting, so far as observations go, in the ultra-violet part of the spectrum.

Now in these two classes of stars, Class III*a*. and Class III*b*. of Vogel, which I have called Class III. and Class IV. to make things easier, in the former we get a spectrum which at present has not been investigated; and we cannot say to what substances the absorptions in stars (there are hundreds of them mind you) which give you that spectrum is due.

But with regard to the stars of the latter class (and there are hundreds of them) they give us absorptions about which there is no question whatever. There the light of the star, instead of being absorbed by iron vapour, by hydrogen vapour, by calcium vapour, and by nickel, and by cobalt vapours and the like, as in the atmosphere of our sun, is absorbed by carbon vapour, and carbon vapour almost pure and simple, for when you have taken these big flutings out of the spectrum, there is little left—which means that when you get rid of the absorption of carbon in the atmosphere of those stars there is very little absorption left. I mean that the remaining spectrum is very simple.

I have already pointed out that it is fair to say that if our sun were hotter its absorption would more resemble the spectrum of its hottest portion, and there we have the spectra such as Dr. Huggins photographed for us in Class I. and Class II. I have just told you that there we really do get the same lines as in our sun during an eclipse, when we can best get at the spectrum of the hottest portion.

Are we to suppose then that if our sun was very much cooler than it is we should get the spectrum of carbon developed in this enormous way? That is a question which at present it is not possible to answer. It is quite probable, but then if that be so, you will see two things: first, that the carbon, *if it exists as such* in such enormous quantities in the sun at the present moment, must be so far outside the region of high temperature that it cannot absorb in that manner. The second point is that it cannot be that particular substance which gives us the continuous spectrum in the photosphere, because if it were we should be certain, I think, to get more indications of bright carbon vapour, both in the spectrum of sunspots and in the spectra of prominences than we do, so that although these stellar spectra may set us thinking about the sun, they are rather more important to us at the present moment for telling us what possibly is not rather than for what probably is.

With regard to the stars with bright lines, the only point that I need make about them now is that it is most important that every endeavour should be made to determine the origin of those bright lines which, as I have already pointed out to you, are not coincident with the lines of hydrogen. But I would rather say what I have to say on that subject in connection with the next part of the comparison which we are making.

In the spectra which have already been indicated to you nothing has been said about change of star-light except at long periods. It has been hinted that possibly a star which at one stage gives you a spectrum of very thick lines, may at other stages undergo changes which will make it a star of the second class, in which we have a greater number of thinner lines and so on.

Here the question of stellar evolution is suggested. On this subject I cannot enter, but a few general remarks may be made. We may say that we now know that comets are clouds of stones, and experiments, to which I will refer again later on, have been made which suggest that if nebulæ are of like nature the differences between cometary and nebular spectra may be explained by differences of temperature, that of the nebula being higher than that of the comet. Now comets ordinarily, *i.e.* when coolest, give us the spectrum of carbon, but when the temperature is increased, as it was in the case of the comet of 1882, sodium and iron are added. Imagine a comet with a nucleus the light of which is absorbed by ordinary cometary vapours, and we shall have the spectrum of a star of the fourth class.

On the nebular hypothesis, supposing, as seen above, that we started with ordinary cometary materials, then, on the beginning of a central condensation which in time is to become a star, as Kant and Laplace suggested, such central condensation should then give us a star of the fourth class. As the energy of condensation increased and the temperature got higher, the spectra would change through the third and second classes, till ultimately, when the temperature was highest, the first class spectrum would be reached. On the slackening down of the temperature of the now formed star, the spectra of the second, third, and fourth classes would then be reproduced, but, of course, now in the direct order.

Nothing so far has been said about changes which instead of taking millions and perhaps billions of years can be undergone in a few days, or weeks, or months.

Careful observations in the heavens have shown a great many years ago that a large number of stars are subject to a considerable change in their brilliancy. The most important work which has been recently done in what we may call the philosophy of variable stars we owe to the diligence of Prof. Pickering of Harvard Observatory in the United States. He has proposed a classification of variable stars, and for the purpose of this lecture I have just to make a slight alteration in his classification, as I did in the other one. First I will tell you broadly what the classification is, and then I will describe as briefly as may be some of the more important details which are of the greatest moment and interest. There is a whole mine of interest here which of course I cannot touch in the time at my disposal.

The first class of these variable stars then may fitly form what are called temporary or new stars—stars which as we have had evidence during the last few years—in 1866 and 1876, and at the end of last year, suddenly burst into visibility in the heavens as if they were new creations, last for a certain time,

and then die away. These stars have bright lines in their spectra.

The second class gives us those bodies which, although form do not appear and disappear with any suddenness comparable to that, yet indicate that there is something very extraordinary going on in them. They also belong to our fifth class of stellar spectra. They have bright lines as well as absorption-lines. These bright lines, however, only last for a short time; but bright lines there are.

Next we get stars not so interesting from the large point of view, in which we get considerable changes in their luminosity extending over very long periods, but their spectrum apparently does not change to any great extent. At least, no change of the spectra of these stars has yet been recorded.

After these, in Class IV. we get small irregular changes, and in fact, Dr. Gould—and there is no greater authority than he—says that every star in the heavens undergoes some slight change in its light at some time or other, but at all events those stars in Class IV. have undergone sufficient change to find themselves recorded among suspected variables, while the change actually has been so irregular that one has really practically not known to what class to assign them; and therefore they have a class of their own.

The next class of variables I will, on Dr. Pickering's authority, define as eclipsed stars: that is to say, in this class the change of light does not come from anything in the star itself, but from something that is happening outside it. What is happening you will see by and by.

Now with regard to our first class—the new stars. The accompanying diagram will give an idea of what has been recorded with regard to them. The information which the diagram affords will also give a pretty fair comparison between these variables and the other classes.

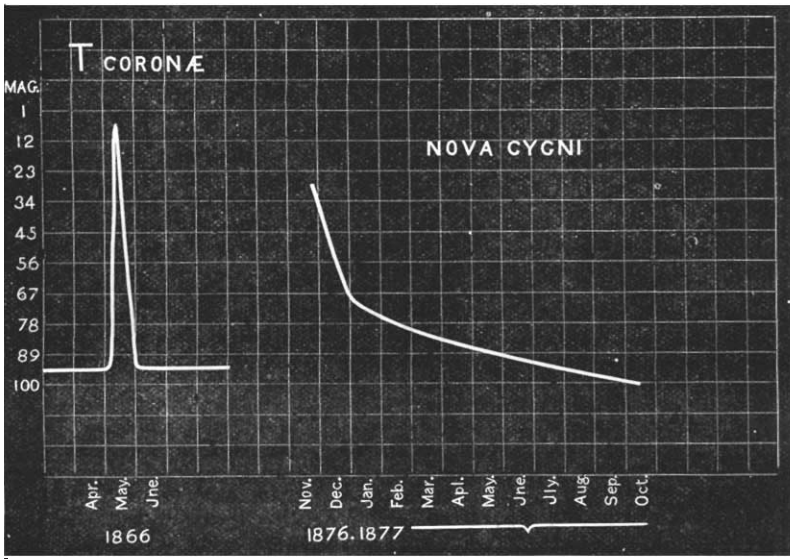

FIG. 24.—Light curves of T Coronæ and Nova Cygni.

In the year 1866 there was a star which had been chronicled for many years as a star between the ninth and tenth magnitudes; for this reason till 1866 its light curve is shown as a straight line. But suddenly, at the beginning of May 1866, this star suddenly burst up into a star of very nearly the first magnitude—between the first and the second. Many observations, as you may imagine, were made on it, and among them Dr. Huggins turned the spectroscope to it, and it was found that the difference between the star when it was between the first and second magnitude, and when it was between the ninth and tenth magnitude, was that in its spectrum when it was most brightly shining we got the spectrum of incandescent hydrogen. We had, in fact, the spectrum of the chromosphere of the sun. It was called "a world on fire." But you know that even the sun is not a world on fire. If it were, and if it were made of the best Welsh coal, we are told that it would last only a few thousand years. But at all events, whatever happened, there was an immense quantity of hydrogen suddenly rendered incandescent, which radiated its light to us.

Almost as suddenly this star went down again, and by the end of the month it had become a ninth or tenth magnitude star, and went about its ordinary business just as if the incident had never happened to it.

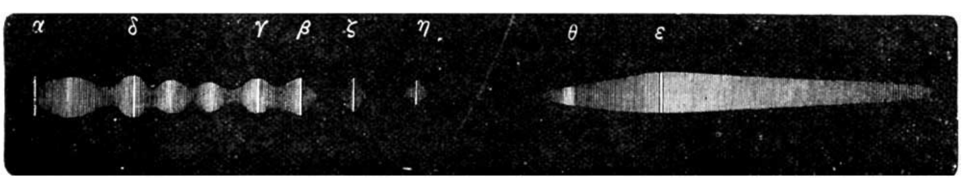

FIG. 25.—Cornu's spectrum of Nova Cygni.

Take the next star in 1876, ten years afterwards. It was called a new star—Nova in Cygnus. The point about this one is that it began suddenly as a star of between the third and the fourth magnitudes. It had had no former history. It had never been mapped. It did not visibly rise to the position of a third or fourth magnitude star from a lower level as the other one had done, but it burst out suddenly. Note the difference in its subsequent history. Its light curve, instead of going suddenly down as the one in Corona did in 1866, goes down gently, and takes nearly a year to get to the tenth magnitude. When it got to the tenth magnitude what happened to it? It gave the spectrum of a nebula. It had ceased to be a star. An interesting point is to inquire—unfortunately we shall never now know—whether or not that mass of matter did not exist as a nebula before 1876.

I have stated that, following close upon the publication of Dr. Vogel's paper on the new star, another paper announced the fact

that the new star had put on the appearance presented ordinarily by the so-called planetary nebulæ.

Of all the lines chronicled by Cornu and Vogel during its stellar stage, only one remained, that, namely, which the latter observer showed to be constantly increasing in brightness while all the rest were waning, and which, moreover, was coincident in position in the spectrum with that observed in the majority of the nebulæ.

The observations of such rare phenomena as the so-called new stars are of such vast importance, and will no doubt ultimately provide us with a clue to so many others of a different order, that we may well congratulate ourselves that this Nova was so well watched, and that there is such perfect completeness and unity in the chain of recorded facts.

It should have been perfectly clear to those who thought about such matters that the word star in such a case is a misnomer

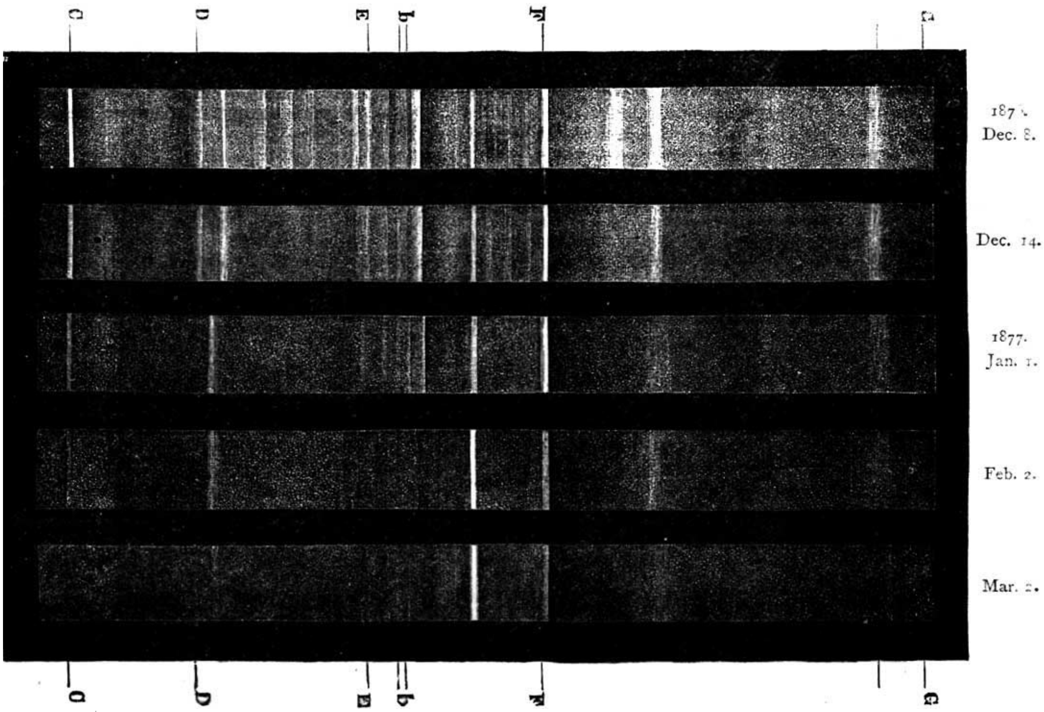

FIG. 26.—Vogel's spectrum of Nova Cygni.

from a scientific point of view, although no word would be better to describe it in its popular aspect. The word is a misnomer for this reason. If any star, properly so called, were to become "a world on fire," were to "burst into flames," or in less poetical language, were to be driven either into a condition of incandescence absolutely, or to have its incandescence increased, there can be little doubt that thousands or millions of years would be necessary for the reduction of its light to the original intensity.

Mr. Croll has shown that if the incandescence observed came for instance from the collision of two stars, each of them half the mass of the sun, moving directly towards each other with a velocity of 476 miles per second, light and heat would be produced which would cover the present rate of the sun's radiation for a period of 50,000,000 years.

A very different state of affairs this from that which must have taken place in any of the Novas from the time of Tycho to our own, and the more extreme the difference the less can we be having to deal with anything like a star properly so called.

The very rapid reduction of light in the case of the new star in Cygnus was so striking that I at once wrote to Mr. Hind to ask if any change of place was observable, because it seemed obvious that if the body which thus put on so suddenly the chromospheric spectrum were single, *it might only weigh a few tons or even hundredweights*, and being so small might be very near us. No motion, however, was perceptible, and Dr. Ball has since stated that he could detect no parallax.

We seem driven, then, from the idea that these phenomena are produced by the incandescence of large masses of matter, because if they were so produced, the running down of brilliancy would be exceedingly slow. J. NORMAN LOCKYER

(*To be continued.*)

FLAME CONTACT, A NEW DEPARTURE IN WATER HEATING[1]

IT is my intention to prove to you on theoretical grounds, and also by experimental demonstration, in such a manner as will admit of no possible doubt, that the present accepted system of water heating, by gaseous or other fuel, is a very imperfect means for an end, and is, both in theory and practice, essentially faulty. My statements may appear bold, but I come prepared to prove them in a manner which I think none of you will question, as the matter admits of the simplest demonstration. I will, in the first place, boil a specified quantity of water in a flat-bottomed vessel of copper; the time required to boil this you will be able to take for yourselves, as the result will be visible by the discharge of a strong jet of steam from the boiler. I will then take another copper boiler of the same form, but with only one-half the surface to give up its heat to the water, and will in this vessel boil the same quantity of water with the same burner in a little over one-half the time, thus about doubling the efficiency of the burner, and increasing the effective duty of the heating surface fourfold, by getting almost double the work from one-half the surface.

The subject is a comparatively new one, and my experiments are far from complete on all points, but they are sufficiently so to prove my case fully. As no doubt you are all aware, it is not possible to obtain flame contact with any cold, or comparatively cold, surface. This is readily proved by placing a vessel of water with a perfectly flat bottom over an atmospheric gas-burner: if the eye is placed on a level with the bottom of the vessel a clear space will be seen between it and the flame. I cannot show this space on a lecture-table to an audience, but I can prove its existence by pasting a paper label on the bottom

[1] A Paper read by Thomas Fletcher, F.C.S., at the Gas Institute Meeting, London, June 9.